ADVANCING STANDARDS
TRANSFORMING MARKETS

Standards Needs for Circular Textiles Workshop Report

Helping Our World Work Better

Contents

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Abstract

The textile industry is increasingly recognizing the need to transition towards a circular economy to address the environmental and social impacts of the industry, particularly as it concerns waste management. However, this transition faces barriers. The development of voluntary, consensus-based standards can help smooth the path toward a circular economy by establishing collaboration and common ground; providing a framework for businesses to operate in; and inspiring consumer confidence in circular products. A recent workshop hosted jointly by the National Institute of Standards and Technology (NIST), ASTM International, and the American Association of Textile Chemists and Colorists (AATCC) explored how standards facilitate the transition toward a more circular economy for textiles. This workshop examined the need for documentary standards and identified several areas where standards would be helpful, including terminology; sorting and grading; recycling, design for circularity; labeling; and digital product passports. This report describes the key discussions and findings of the workshop and highlights areas where specific standards needs were identified. It concludes with recommendations for the next steps and a proposed roadmap to begin developing the identified standards to enable circular textiles.

Figures & Tables

Acronyms

AATCC	American Association of Textile Chemists and Colorists
CE	Circular economy
COC	Chain of custody
DPP	Digital product passport
EoL	End-of-life
EPA-NRS	EPA National Recycling Strategy
EU	European Union
ISO	International Organization for Standardization
LCA	Life cycle assessment
NACTR	National Association for Charitable Textile Recycling
NIST	National Institute of Standards and Technology
SDO	Standards development organization
SMART	Secondary materials and recycled textiles
WTO	World Trade Organization

i. Introduction

In recent years, efforts have increased to transition away from a linear (take, make, use, discard) economic model toward a more efficient and resourceful circular economy (CE). For textiles, this includes extending the life of garments through improved design, reuse, repair, and recycling of garments at end-of-life (EoL). Significant efforts are underway across industries, governments, and research communities to facilitate this transition, but challenges persist.

In 2021, the U.S. National Institute of Standards and Technology (NIST) held a three-day workshop aimed at understanding the barriers and opportunities facing textile circularity, the outcomes of which are documented in [1] and [2]. Based on the findings of that workshop and continued engagement with stakeholders, the need for voluntary, consensus-based standards was identified as an enabler of this burgeoning circular textile industry. Therefore, in collaboration with ASTM International and the American Association of Textile Chemists and Colorists (AATCC), NIST hosted a follow-on workshop to identify specific needs for new standards. This report summarizes the findings from that workshop and describes the types of standards needed across the textile value chain. In addition, this report provides some information about the order in which these standards could be developed based on the current state of this emerging field.

1.1 BACKGROUND AND MOTIVATION

While textiles are components in bedding, clothing, apparel, medical, and other applications, the fashion segment dominates the market. In 2023, the global textile market was valued at over 1.8 trillion U.S. dollars and is expected to increase, largely driven by the fashion industry and the growth of e-commerce platforms [3]. That same year, roughly 93 billion units of textile and apparel were imported into the U.S., approximately a third of which came from China [4]. The U.S. is expected to remain a significant cotton producer in the industry, owing to rising textile product demand from various end-use sectors [3]. Because of this, textile production is growing rapidly, demanding increased resource inputs such as land, water, and energy. At the same time, the volume of textile waste generated is increasing year-over-year. According to the U.S. Environmental Protection Agency (EPA), the amount of textiles sent to landfills increased 78 % between 2000 and 2018, from 9.5 million tons to nearly 17 million tons annually [5]. For reference, the total waste stream grew by 10 % over this same timeframe. Per capita, textile waste grew 55 % over the same period, indicating that the increased textile waste generation is not due to population growth alone [6]. Per the U.S. EPA's waste statistics and U.S. Census data, each American discarded, on average, 47 kg (103.5 lb) of textiles in 2018. Research indicates that only about 15 % of used textiles are diverted from the landfill, and less than 1 % are recycled back to fibers [6, 7, 8].

i. Introduction

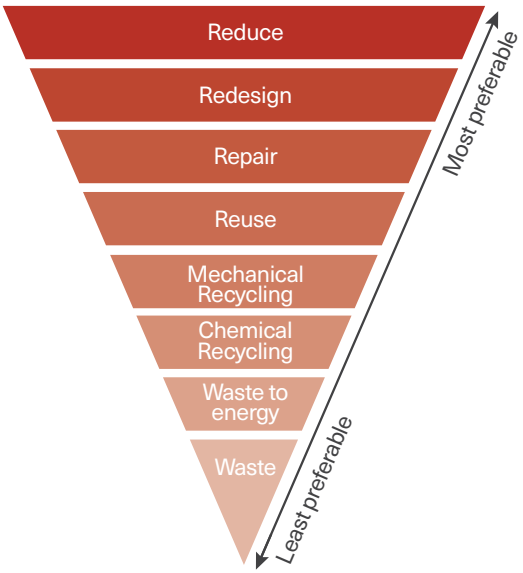

Figure 1 — Value Hierarchy of Textiles Management in a Circular Economy (adapted from [9] and [10])

This current linear textile production and consumption model and its inherent limitations resulting from resource utilization and excessive waste generation necessitate a strategic transition towards a more circular economic model. Note that this report uses the term "waste" to represent textiles that no longer suit their desired purpose or function and are discarded. In a CE, waste is viewed as a resource, meaning mechanisms are needed to capture this waste stream and reprocess it back into the economy. As displayed in Figure 1, the value hierarchy for circular textiles prioritizes the pathways that maintain the highest material value for the most extended period of time. Ultimately, the generation of textile waste should be minimized as much as possible through reduced inputs, improved design, repair, reuse, and recycling. These life-extension practices are broadly referred to here as re-X.

Technological, social, and economic challenges currently present obstacles to achieving textile circularity [11]. A key challenge lies in the varied and complex nature of textile waste, which encompasses discards from manufacturing, customer returns, and used garments that are no longer desired. Additionally, textile products comprise various fiber types ranging from natural to synthetic, and increasingly, products are made from fiber blends. To add further complexity, textile products often contain non-fibrous elements such as fasteners (e.g., zippers, buttons, etc.) and chemical coatings, finishes, dyes, and additives to achieve desired performance or aesthetic properties. Each of these factors must be considered as solutions are developed due to their varying compositions and needs.

Social challenges also hinder textile circularity as the textile ecosystem has largely shifted away from durability and repair in favor of fast fashion and disposal. As a result, consumers are often unsure how to participate in a circular economy for textiles. In this sense, customers may not understand how to identify circular products or the benefits of purchasing them, sometimes at a price premium. Furthermore, the repair and recovery sector is becoming less prevalent, leaving consumers struggling to identify ways to access repair options for textiles or where and how to direct unwanted textiles for reuse or recycling. This lack of awareness, coupled with a scarcity of options for proper textile disposal, can lead to usable textiles being incinerated or landfilled. Economically, the cost to recover and recycle textiles currently exceeds the costs associated with using primary (virgin) materials in textiles. Until efficient and cost-effective recycling processes are scaled, recovered and recycled textiles will be unable to compete in the mainstream market.

Addressing these challenges and improving the circularity of textiles requires technological, social, and policy strategies. Cross-sector collaboration and interoperability of systems are crucial to facilitate the sharing of data and information and to foster the development and uptake of circular solutions. Standards could play an important role in this transition as they can harmonize language and processes across the value chain and between sectors; support market development and stabilization; and ultimately build trust in the system (see

i. Introduction

Section 2). To assess and understand the need for standards, NIST, the AATCC, and ASTM co-hosted the "Workshop on Identifying Standards Needs to Facilitate a Circular Economy for Textiles" in October 2023. This virtual event convened stakeholders from across the value chain and life cycle of textiles, including brands, collectors, recyclers, researchers, consultants, and policymakers, to discuss standards needs in the following key areas:

- Terminology
- Textile sorting
- Input specifications for textile recycling
- Guidelines for circular design
- Digital product passports

Appendixes A and B provide the full workshop agenda and speaker lineup, respectively. This report summarizes the role of standards in textile circularity (Section 2); standards identified in the workshop to support textile circularity (Section 3); and the next steps and processes for standards development in this area (Section 4).

ii. The Role of Standards

Standards act as guidelines for ensuring consistency and organization for a community. They offer harmonized, agreed-upon rules, guidelines, or characteristics for common and repeated use [12]. Table 1 presents some common types of documentary standards. Typically, these standards contain definitions, technical specifications, or other criteria designed to be used consistently by stakeholders, thereby increasing the reliability and effectiveness of goods and services. Table 1 provides common types of documentary standards consolidated from [13, 14, 15]. Standards development organizations (SDOs) active in textile circularity include ASTM, AATCC, and the International Organization for Standardization (ISO). ASTM has two committees involved in circularity and textile standards: the committee on sustainability (E60), which focuses on sustainable development standards; and the committee on textiles (D13), which concentrates on textiles specifically. These ASTM committees generally develop specifications and test methods for textiles and typically focus on the physical properties of textile materials. AATCC develops standard methods and procedures for the chemical properties, colorfastness, and wet testing of textile materials. The ISO Technical Committee (TC) 323 is working to standardize the circular economy field on an international scale. ISO standards are developed by consensus, with each country involved getting one vote. The American National Standards Institute (ANSI) has appointed the committee on sustainability to coordinate with the U.S. Technical Advisory Group (TAG) to ISO/TC323 and report their activities to ANSI. ANSI then represents U.S. interests in ISO/TC 323 [16].

Standards can be established at various international, national, and company-specific levels. Typically, standards development involves convening relevant stakeholders to develop nominal requirements, which are then approved by consensus through a recognized body [17]. Most standards relevant to circularity are voluntary consensus standards, meaning that parties interested in the standard cooperate to develop those standards, and compliance is not regulated or mandatory. That said, voluntary consensus standards are significant and influential, as they may be adopted widely and openly, written into contracts and agreements, and used to create federal policies and laws [18].

Developing open, consensus-based standards is critical in the transition to a CE. Harmonizing and standardizing circularity metrics, methods, tools, and practices across the supply chain would foster information and data sharing, improve market stability, and enable consumer trust. Standards can play a crucial role in demonstrating regulatory compliance and helping inform effective policy development. Establishing a common language, technical details, specifications, performance requirements, and standards can help guide the development of government regulations and bridge regulatory gaps. This can include unifying industry practices and developing definitions, best practices, or specifications not currently addressed through state or federal regulation. Standards can support increasing economic momentum or technological advancement while encouraging innovation [19, 20].

ii. The Role of Standards

Table 1 — Common Types of Documentary Standards

TERMINOLOGY	Contains definitions of terms and explanations of symbols, abbreviations, and acronyms.
GUIDES	Collections of information or series of options that do not recommend specific courses of action. They generally inform people of the knowledge and approaches in given subject areas.
PRACTICE METHODS	Instructions for performing one or more operations that do not generate a test result. Examples include application, assessment, cleaning, collection, inspection, preparation, sampling, and training.
CLASSIFICATIONS	Systematic arrangements or divisions of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use.
SPECIFICATIONS	Requirements that a material, product, system, or service must meet. The specification identifies test methods for determining whether each requirement is met. These requirements can include physical, mechanical, or chemical properties and safety, quality, or performance criteria.
TEST METHODS	Defined procedures that generate test results. Examples include identification, measurement, and evaluation of one or more qualities, characteristics, or properties.
REPORTING METRICS	Standard description of what an organization should be doing or reporting (e.g., Global Reporting Standards).
CODES	Descriptive standards, especially safety-related ones, are often adopted into laws (e.g., ASME B31 codes for pressure piping).
CORPORATE STANDARD OPERATING PROCEDURES (SOPS)	A description of standard procedures for operations that are based on industry or company-specific best practices and laws.

Consensus-based, industry-wide standards can also facilitate transparency and trust across the CE, increasing consumer confidence in goods and services. This includes, for example, establishing metrics and methodologies to ensure that materials are traceable and environmental impact assessments are consistent, reliable, and verifiable such that resulting “green” claims can be substantiated. Certification programs with labeling schemes can attest that standards have been followed and effectively convey a trusted, accurate message to consumers. Furthermore, consensus-based standards foster market development by leveling the playing field and promoting equity between large and small companies and developed and developing countries by coordinating consensus on definitions, specifications, and best practices. Such equity fosters strong market competition, encouraging innovation and lowering prices. International standards can play a crucial role in globalized supply chains, such as those in the textile sector.

ii. The Role of Standards

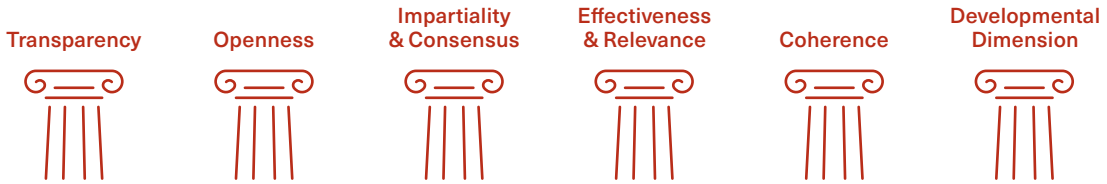

Figure 2 — Key Principles of Standards Development as Highlighted by the World Trade Organization [21]

The World Trade Organization (WTO) outlined six fundamental principles (Figure 2) for developing international standards, guides, and recommendations. These six principles are transparency; openness; impartiality and consensus; effectiveness and relevance; coherence; and developmental dimension [21].

Transparency: This means that necessary information on standards under development, as well as proposals for future standards being considered, should be openly shared. Sufficient time should be given to obtain comments or feedback on draft standards, and a process for handling these comments should be provided. When a standard is identified to be developed, the public should be notified early enough to allow engagement with relevant communities. This notice should provide information about the planned scope of the standard. Once comments are adjudicated and a standard is ready to be published, publication should be prompt so that interested parties can access the final version of the standard.

Openness: Membership in an SDO should be open and free from discrimination at all stages in the standards-development process. This includes activities such as identification of new standards-development efforts, technical discussions, comment submission, review of published standards, voting and standards adoption, and dissemination of the standard.

Impartiality and Consensus: All parties should have equal opportunities to contribute meaningfully to a standard to ensure the process is unbiased. Procedures should be in place to ensure that viewpoints from all participants are considered and to adjudicate any points of disagreement in the process. Effectiveness and Relevance: Each SDO must ensure that standards avoid barriers to trade, are responsive to market and regulatory requirements, and reflect scientific and technological advancements. They should not adversely impact global markets or fair competition, nor stifle innovation. The needs of all regions and countries involved should be considered fairly when developing standards. When possible, standards should focus on performance-based requirements instead of prescriptive specifications that can stifle innovation and limit competition. Standards should also be reviewed regularly to ensure they are up-to-date and effective.

ii. The Role of Standards

Coherence: Communication and cooperation between standards bodies are crucial to ensure that efforts are distinct among SDOs to prevent conflicting international standards in the marketplace, which is represented in the WTO principle of coherence. Finally, the developmental dimension should be considered in standards development. Many developing countries may be disadvantaged when participating in standards-development efforts, but they must be included to uphold the principles of impartiality and openness discussed previously. Actionable solutions to facilitate the participation of developing countries should be pursued by SDOs.

Developmental Dimension: The rapidly evolving field of textile circularity requires a dynamic approach to standards development. Existing SDOs like ASTM and ISO already require standards to be reviewed and updated regularly, acknowledging the industry's dynamic nature. However, data-driven standards will become critical to keeping pace with this rapidly evolving industry moving forward. This includes considering data on customer behavior, market capacity, and infrastructure gaps to ensure feasible regulations and accurate progress tracking. Additionally, exploring component remanufacturing and establishing automation standards can unlock new avenues for circularity in this industry.

iii. Standards Needed to Support Circular Textiles

This section outlines areas for standards development based on the workshop presentations and discussions. They have been categorized into: 1) Terminology Standards, 2) Textile Sorting and Grading to Enable Reuse and Repair, 3) Textile Recycling, 4) Design for Circularity, and 5) Digital Product Passports.

3.1 TERMINOLOGY STANDARDS

Terminology standards facilitate interoperability across stakeholders and create a common language foundation upon which markets, policies, and other standards are built. It was noted that terminology is also vital for getting customer buy-in to a CE, as agreed-upon terms for technical and marketing claims like "vintage" and "pre-owned" can increase trust in secondary textiles and, in some cases, add value. The textiles ecosystem, particularly consumer apparel, brings together diverse stakeholders who all use terms differently. To communicate clearly, it is essential to ensure that everyone working together to achieve a consensus-based standard understands the language that others are using. Communication among different groups, such as the charity/thrift sector and the recycling community, will be essential to identify terms that need to be clearly defined.

Workshop participants identified several organizations that have compilations of relevant definitions of terms that may be important for circular textiles. These organizations should be part of the discussion, as they represent different stakeholders in the textiles value chain, and these existing resources should be consulted as terms are defined to ensure clarity and redundancy. Whenever possible, new standardization efforts should attempt to harmonize terminology with existing documents (e.g., [10]) to avoid confusion. Some potential resources to consult for terminology include:

- U.S. Government organizations, e.g., the U.S. EPA and the Federal Trade Commission (FTC). The FTC's Green Guides contain principles for making green marketing claims, including definitions for terms such as recyclable, recycled content, and sustainable [22].
- Industry-specific protocols (e.g., Salvation Army, Goodwill, mechanical and chemical recyclers)
- Non-profit and interest group documents (e.g., Textile Exchange, Ellen MacArthur Foundation, Secondary Materials and Recycled Textiles (SMART), the National Association for Charitable Textile Recycling (NACTR))

Workshop participants discussed ASTM's terminology standardization process as well as a list of existing terminology standards that may be relevant to circular textiles, which include:

- Standard Terminology for Sustainable Manufacturing (E2987)
- Standard Terminology for Sustainability (E2114)
- Committee D13 on textiles has a list of ~115 terms, and ASTM has a searchable dictionary function available through their website.

To facilitate communication and harmonization around the world, international standards, guides, and documents should also be consulted, such as those produced by the EU or ISO.

iii. Standards Needed to Support Circular Textiles

A conversation took place throughout the workshop highlighting terms that different stakeholders and communities within the value chain used. Some such terms are captured in Table 2 as a starting point for consideration as standards are developed. Terminology can be developed as needed in the context of the development of other standards. For example, terms needed for sorting could be defined in the context of a sorting-specific standard. These terms can then become part of the broader lexicon for an SDO through their terminology-management process.

Table 2 — Examples of Unclear or Confusing Terms Identified in the Workshop, Some of which are Defined in Other Documents or Standards

MATERIAL / FEEDSTOCK	EoL PATHWAYS	STYLES AND MARKETING TERMS	VALUE-ADDED PROCESSES	SOURCE
– Textile – Biodegradable – Bio-based – Disruptor	– Reuse – Recycle, Reclaim, Recover – End of use / End of life – Fiber deconstruction – Repurpose – Donation – Resell – Open loop – Closed loop	– Vintage – Pre-loved – Worn wear – Made with recycled materials	– Sorting – Recycling rate – Downcycling – Upcycling – Contaminants/ Contaminated – Grading	– Pre-consumer – Post-consumer – Post-industrial – Residential waste – Non-residential waste – Commercial waste – Institutional waste

3.2 TEXTILE SORTING AND GRADING TO ENABLE REUSE, REPAIR, AND RECYCLING

Textile waste streams are largely heterogeneous, comprising various material types and blends, different colors, garments of various ages and conditions, and fasteners like zippers and buttons [23, 24]. However, recycling and most other re-X strategies currently require homogenous feedstocks, so textiles collected for cascading secondary uses and end markets must first be sorted. Post-consumer textile waste streams (waste generated by consumers after use) tend to be more heterogeneous than pre-consumer streams (waste generated during manufacturing). Workshop participants identified two categories of problems associated with textile sorting: limitations of manual sorting and challenges in identifying fiber types. Currently, most textile sorting and grading is performed by hand, and the pathway to scale up sorting from manual to automated processes is challenging because of the large volumes and highly variable nature of the waste stream.

iii. Standards Needed to Support Circular Textiles

3.2.1. IMPORTANCE OF SORTING FOR A CIRCULAR TEXTILE ECONOMY

Sorting is an essential step for circularity as efficient sorting dictates textiles' flow through the value hierarchy and maintains value through resale (potentially repair then resale) or recycling. However, current sorting practices face significant challenges due to missing or inaccurate labeling, disruptive components (e.g., buttons, zippers), and the variability of textile materials and blends. To overcome these hurdles, the industry needs to standardize sorting and establish clear bale specifications to ensure consistent feedstock quality for recycling. The sorting and recycling industries need to collaborate to achieve the best possible outcomes for a circular textile industry. Social enterprises should also be included in these discussions because they can provide valuable collection and processing infrastructure, ensuring textiles are directed to their highest and best use. Collaboration with brands is also necessary to establish feedback loops and improve product labeling.

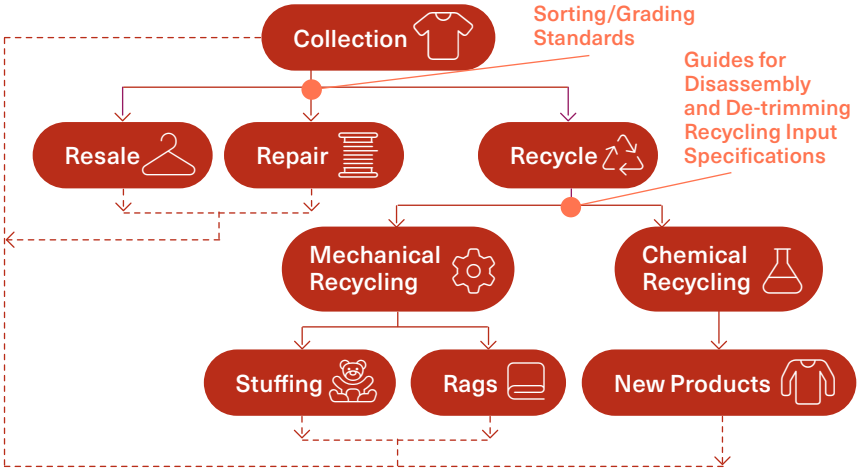

Figure 3 —Idealized post-collection pathway to improve circularity for textiles with indications of where standards can play a role. Dotted lines indicate a secondary stream (e.g., repaired items can be resold, and stuffing and rags can be recollected).

3.2.2. MULTI-TIERED SORTING STRATEGIES FOR RESALE (AND RECYCLING)

Whether sorting for resale or recycling, a key challenge is the varying needs of downstream markets. Debate exists on how to prioritize sorting—by material or by garment type. Sorting may require a multi-tiered strategy to maximize the value of post-consumer textiles. In addition to improving sorting, fostering strong resale markets is crucial for a circular textile economy. Workshop participants suggested a simple rule of thumb that used clothing retains 15 % to 20 % of its original cost in the reuse market. Low-cost, fast fashion garments flooding the market are seen as detrimental to a textile's value for reuse or resale. Some workshop participants discussed the idea of standards for grading (which is a type of sorting) of used textiles with the goal of identifying those in the best condition for resale. The charity

iii. Standards Needed to Support Circular Textiles

and thrift industries are often the "front line" in grading garments. Many charities and thrift stores require outlets for clothing that does not easily sell so that they can continue to process new donations and rotate stock. A grading strategy could also be applied to incoming materials to curate the most desirable (highest value) textiles for resale or repair, followed by resale, and to remove those that are unlikely to be resold (e.g., contaminated or damaged beyond repair) and divert them to a recycling process. Best practices or process guides could be developed to help standardize these processes and make them more harmonized and efficient.

Some fashion brands prefer to limit or prohibit the resale or secondary use of their products, particularly unsold merchandise [25]. The workshop explored the possibility of social enterprises offering certificates of destruction for items that a brand does not want to be resold, but that could still be diverted from a landfill or incineration process and towards a recycling process. This is similar to companies that destroy copyrighted products in other industries.

3.2.3. CHALLENGES AND OPPORTUNITIES WITH GARMENT LABELS

Clear and accurate labels are important for all re-X pathways. For resale, they help consumers identify the brand, size, style, materials, and care of the garment. That information is similarly relied upon for repair. However, in the U.S., the FTC enforces textile labeling requirements, which were originally intended to provide information for consumers (i.e., consumer-facing) and not intended for end-of-use pathways such as sortation [26]. As a result, garment labels cannot be relied upon when sorting materials for recycling processes. Workshop attendees said that labels are "unreliable" as they often contain inaccurate or incomplete information about the material composition of garments, hindering sorting and recycling efforts. In addition, workshop participants noted that many existing labels do not contain enough information to help sorters identify a garment's minor (less than 5 %) components; hidden components such as core-spun elastic yarns with other fibers as the face layer; additives; multilayer fabrics; or fastener materials (e.g., zippers, buttons). Furthermore, it is not uncommon for printed labels to become worn and illegible or removed before donation, resale, or recycling. Therefore, clear standards are needed to drive garment labeling improvements to support consumers and enable circular end-of-use pathways. These could include specifications for the information contained in labels, label durability, and guides for using digital labels or digital product passports (see Section 3.5).

3.2.4. ADDRESSING DISRUPTIVE COMPONENTS IN GARMENT SORTING

Workshop participants discussed the challenge posed by components such as buttons, zippers, and fasteners in garments, which were broadly referred to as "disruptors." Since many recycling processes cannot accept these components, garments with these disruptors must be identified during sorting. Many recycling processes require a "de-trim phase" after sorting so that these components can be removed prior to sending material to a downstream operation. There was significant discussion among workshop participants about the potential for automated deconstruction of garments that can address both rigid and soft materials to facilitate efficient garment repair and material recovery. Recycling and secondary markets for

iii. Standards Needed to Support Circular Textiles

trims like zippers and buttons should be explored to maximize resource recovery. Depending on the chemical makeup of disruptive components and the recycling process selected, there can be significant differences in the input requirements and the ability to accept these mixed materials as process inputs – where some chemical recycling processes can handle them while others cannot. This highlights the need for clear, standardized input specifications for recycling processes, as discussed in the next section, and a process for information exchange between sorters and recyclers, especially as recycling technologies evolve.

3.2.5. TECHNOLOGICAL ADVANCEMENTS AND BEST PRACTICES IN SORTING FOR RECYCLING

Sorting garments for recycling is a multi-tiered effort that may require several steps. For example, if a legible label remains on the garment, it could be examined to provide information on the fiber content. The garment could then be interrogated using a technique such as near-infrared spectroscopy to further identify the fiber types, finishes, dyes, and other components. Colorimeters or other light-based tools could be used to further separate materials by color. Similar types of garments could be grouped for efficient de-trimming or even put through an automated process such as computer vision or hyperspectral imaging. However, all of these different steps would be aided by a standard guide to sorting for recycling that could provide guidelines such as the optimal order of operation for these sorting steps. In addition, standardized guidelines for prioritizing one aspect (such as material type) over another (such as color) would help make sorting more uniform, efficient, and effective.

Developing harmonized input or "bale" specifications for post-consumer textiles designated for a recycling process would significantly enable the scaling-up of these processes and provide a stable supply of consistent feedstocks for recycling processes. However, harmonization is challenging as existing processes operate in a relationship-dependent way due to the high variability of post-consumer textile materials. This variability includes garment form factors; fiber types and qualities; color; the presence and characteristics of disruptors; and contaminants. Many post-consumer textiles have stains such as grease or oils; additives like dyes, finishes, or prints; and mixed material components. These could be considered contaminants, depending on the selected recycling pathway. A better understanding of how contaminants affect recycling is also essential to scale up for sorting. This could lead to carefully developed bale specifications that include the maximum allowable contamination levels for recycling feedstock. Transparent and frequent communication between sorters and recyclers would help sorters understand demand signals, costs, and standardized feedstock specifications to optimize their operations for recycling. In addition, since textile recycling is a nascent and rapidly evolving field, continued communication to help sorters stay abreast of advancements in this field—potentially leading to revised inputs—is critical and can help build trust and transparency in this field. Innovation is needed to develop better material identification, sorting, and pre-processing techniques to reduce feedstock acquisition and processing costs. For example, complex multi-layer garments or those with hidden components (e.g., liners) are difficult to identify and deconstruct. By addressing the challenges, investing in innovation, and establishing

iii. Standards Needed to Support Circular Textiles

clear standards, stakeholders can create a system that maximizes resource recovery, minimizes waste, and promotes a circular economy for textiles.

3.2.6. STANDARDS NEEDS FOR TEXTILE SORTING AND GRADING

In summary, the following standards needs were identified through the workshop presentations and discussions:

Grading, Sorting, and Bale Specifications:

- Best practices for grading for resale, repair, and recycling
- Best practice methods for sorting textile materials for recycling
- Classifications of textile materials to enable advanced sorting
- Specifications for sorted post-consumer textile bales designated for recycling (including contaminant limitations)
- Test methods for rapid identification of textile composition (e.g. fiber content, additives, etc.)

Labeling:

- Specifications for garment labels, including information about:
  - Material composition (including minor components, fasteners, and hidden layers)
  - Additives and finishes
  - Care instructions

As discussed, standardized terminology is a critical component of these efforts, which will be essential for advancing and harmonizing sorting and grading operations and enabling efficient re-X pathways. Development of these standards requires communication between graders, sorters, and recyclers regarding system capabilities, market dynamics, and demand signals. As such, collaboration is essential among stakeholders (including social enterprises) to address challenges and promote a circular textile economy.

3.3 TEXTILE RECYCLING

Sorting and recycling are intricately entwined in a circular textile ecosystem. Robust sorting processes, facilitated through sorting guides and bale specifications, support recycling processes with well-defined and consistent inputs. This, in turn, helps recyclers produce high-quality recycled materials to drive circularity for textiles. Many of the standards needed to facilitate recycling were identified in the previous section. This section will discuss some of the challenges and opportunities associated with textile recycling processes and discuss additional standards needed in this space. Workshop participants estimated that approximately half of collected garments can be downcycled into materials like shoddy and rags. While this extends the life of the textile material, the value of these materials remains low, and the ability to mechanically or chemically recycle those downcycled products may be inhibited by further processing or contamination during use (e.g., oil contamination on industrial rags). Shredding processes, which are frequently required for downcycling or a precursor to recycling, are often inhibited by disruptors (e.g., zippers) or materials like elastane.

Textile recycling technologies, including mechanical and chemical recycling, aim to transform used textiles back into raw material feedstocks. While these technologies

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offer promising solutions for reducing waste and promoting circularity, they face several technical challenges, especially in areas like disruptor removal, blend separation, feedstock quality, and cost reduction. Mechanical recycling tends to generate shorter fiber lengths, which limits the number of cycles through which a material can be mechanically recycled. As discussed, emerging technologies can offer solutions for recycling blended materials, but additional work is needed in this space to expand this potential. The need for recycling processes that can handle stretch components such as elastane was highlighted as a significant topic that requires additional investment. Another challenge facing textile recycling is establishing material flows that optimize complementary mechanical and chemical recycling pathways. While some materials are effectively recycled mechanically, others may be more suitable for chemical recycling.

In addition, while fiber-to-fiber recycling is only practiced on a very small scale, fiber-to-fiber recyclers have faced a gap between stated purchase commitments from the fashion community and the actual purchase of their recycled fiber [27]. Building transparency through open and clear communication and collaboration across the textile supply chain is essential. One way to improve transparency is by creating standard guidelines for chain of custody and recycled content reporting. While closed-loop recycling may be ideal, blending recycled materials with virgin fibers and chain of custody validation (e.g., through mass balance accounting) can be more feasible in the near term. Standards can ensure accurate reporting on recycled content and bridge the gap between corporate commitments and actual purchases. Additionally, differentiating between pre-consumer and post-consumer textile waste is essential for accurate tracking and transparent reporting of recycled content. Guidelines for classifying pre- and post-consumer waste would enable clear and consistent reporting within the recycling system.

Collaboration between fiber-to-fiber recyclers and brands is critical to bridging the gap between brand commitments and actual purchases. Comprehensive and implementable third-party certification systems are crucial to empowering brands in their material and product choices. Ultimately, the ideal outcome for the recycling industry is a universally accepted framework for textile recycling. This framework would outline inputs, outputs, and supply-chain connections, providing a clear roadmap for the industry and fostering efficient and sustainable textile recycling practices throughout the value hierarchy.

3.3.1. STANDARDS NEEDS FOR TEXTILE RECYCLING

In summary, the following standards needs were identified through the workshop presentations and discussions:

Technical Best Practices

- Best practices for removing disruptive components such as zippers and buttons or contaminants such as dyes or prints
- Test methods for identifying and recycling blended materials (including stretch components like elastane)
- Best practices for disassembly and de-trimming (e.g., disruptor removal)

iii. Standards Needed to Support Circular Textiles

Transparency and Validation:
- Best practices for tracking material chain of custody and reporting recycled content (including sources, provenance, form factor, and quantity)
- Guidelines for what constitutes pre-consumer and post-consumer textile waste that can be used to validate manufacturer content claims
- Specifications for digital garment labels or passports with material composition information and care instructions (see Section 3.5)

3.4 THE ROLE OF BRANDS AND DESIGN IN PROMOTING CIRCULARITY

The textile industry faces a significant challenge balancing consumer demand for affordable, fashionable clothing with the rapidly increasing challenges associated with textiles at EoL. This section explores the role that brands can play in promoting circularity, with a particular focus on tools for designers to better understand the downstream impacts of their decisions. The workshop discussions highlighted the need for clear and practical standards to guide circular design in the textile industry, which are further explored below.

3.4.1. BRANDS AS DRIVERS OF CIRCULARITY

The workshop included significant discussion about the role of brands in circular product development. Generally, brands were encouraged to integrate circularity priorities into their brand values and communicate these clearly to consumers. Transparency around materials, construction, and EoL options is essential to build consumer confidence in circularity. This journey may not look the same for every brand. For example, one company may emphasize keeping products in use for as long as possible through design for durability, offering repair services, and maintaining a resale platform. Another company might prefer to leverage a circular supply chain, creating products made to last from safe, recycled, regenerative, or other, more sustainably sourced material combined with lower impact dyeing, printing, or finishing processes that can circulate in the economy many times. Brands can also encourage and enable circular consumer journeys. For example, brands can help educate consumers and provide convenient ways for consumers to engage in circular fashion, where products are used longer before being repaired, reused, and recycled.

However, as highlighted in the workshop, brands play an influential role in facilitating textile circularity through material and product design. The consensus from this session is that the industry, as represented at the workshop, welcomes the development of a design guide for textile circularity. By collaborating with designers, brands, and other stakeholders, the development of clear and practical standards can facilitate the implementation of circular design principles and move the industry toward a more sustainable future.

3.4.2. THE NEED FOR CIRCULAR DESIGN GUIDES IN THE TEXTILE INDUSTRY

The textile industry has established design workflows prioritizing efficiency, functionality, and consumer appeal, but these approaches often fall short in considering a garment's environmental impact throughout its life cycle. Design guides focused on circularity are essential to bridge this gap and contribute to a more circular textiles industry. They formed a central discussion point in the workshop. These guides would provide designers with the knowledge and tools they need

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to create aesthetically pleasing garments designed for durability, repairability, deconstructability, and, ultimately, recyclability. Workshop participants reiterated the need for common terminology, as it was discussed how providing designers and brands with precise tools and definitions for circular design concepts can help facilitate adoption and implementation. Design for circularity requires a holistic approach that integrates EoL considerations throughout the entire product life cycle. However, circular design alone cannot make a product circular. Establishing a circular ecosystem encompassing systems, infrastructure, and circular business models is necessary to fully realize circularity.

3.4.3. CHALLENGES OF INTEGRATING CIRCULARITY INTO EXISTING DESIGN PRACTICES

The textile industry, particularly the apparel design industry, has existing design guidelines and workflows that must be considered when developing tools and standards to guide circular design. There have been efforts to develop circular design guidelines for the textile industry; for example, the U.S. EPA National Recycling Strategy (EPA-NRS) has some design guidance that applies to textiles, but these guidelines can be challenging to operationalize practically for textile designers. For instance, EPA-NRS encourages designers to "increase consideration of recoverability and sustainability in the design of new products" and "improve the accessibility of data for product design and procurement." However, specifics for how a designer might access clear, transparent, and trustworthy tools to implement these suggestions would be helpful when designing a new product. Currently, the committee on sustainability (E60) is working on an overarching "New Guide for Principles for Circular Product Design" [28]. This standard is envisioned to have industry-specific components, one of which could be dedicated to circular textiles in the future.

3.4.4. BALANCING DURABILITY AND RECYCLABILITY TRADEOFFS IN GARMENT DESIGN

A noteworthy theme from the workshop related to the development of standard design guides is the consideration of tradeoffs with the end goal of product design. One prominent struggle designers face is choosing between design for durability and design for recyclability. Often, these design features conflict, and finding the right balance between durability and recyclability is crucial. This may involve different approaches for different types of garments and materials. For example, it makes more sense to design for recyclability for products such as socks and undergarments, which are less likely to be resold or repaired. On the other hand, the design of outdoor apparel may prioritize durability, which likely necessitates a high level of complexity in the garment design to meet the desired performance requirements. This may mean using multi-layer components, including layers of complex finishes, reinforcements and fasteners, and incorporating a mix of fiber types. Similarly, selecting materials, dyes, and finishes that better withstand multiple washes also extends the garment's useful life and maintains resale value. However, while these design choices may extend the garment's useful life, they may make it more difficult to recycle at EoL.

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Designer education about the impact of material selections on circularity and the development of valuable tools to guide design decisions is essential. A compromise might be to make a garment more easily deconstructed and design specific components to be easily recycled, for example, using mono-materials in particular elements of the garment. Consideration of EoL also encompasses ideas such as garment repair and resale, all of which extend the useful life of a garment. Selections like choosing a metal rather than plastic zipper can make the garment more easily repairable and help enable life extension, but it also adds another material type to the components list that would need to be de-trimmed before recycling.

3.4.5. THE IMPORTANCE OF DATA SHARING AND FEEDBACK LOOPS

Another theme that emerged from this session was the need for improved exchange of information and data between different stakeholders (such as the brands and repair, resale, and recycling communities) to enable designers to make more circular design choices. Strategies are also needed to address the time gap between designing garments for circularity and obtaining data on their actual lifespan and EoL practices;it can take so long to track the lifespan of a garment that the information is no longer relevant to the designer. Still, data from the garment repair industry could be more rapidly integrated into design decisions. As brands and designers attempt to incorporate more circular considerations into their products, data collection and analysis will become essential for understanding the effectiveness of circular design strategies and identifying further areas for improvement. Design guidelines could encourage brands to establish a feedback portal for consumers to provide specific information about their garment use.

3.4.6. STANDARDS NEEDS FOR CIRCULAR DESIGN

The consensus from this session was that the industry would welcome a design guide for textile circularity. Some specific standards considerations include:

- Material specifications for preferred fibers, compositions (including limitations on blends), and restrictions on harmful substances for circularity.
- Test methods for durability to assess garment longevity for different use cases (e.g., outdoor versus intimate apparel).
- Best practice guides for EoL considerations: deconstruct-ability, repairability, recyclability considerations, and potential disassembly methods.
- Guides for material identification and traceability throughout the value chain (e.g., Chain of Custody).
- Specifications for recycled content and material composition.
- Reporting metrics for measuring and reporting the impacts of circular design.

3.5 DIGITAL PRODUCT PASSPORTS

The workshop discussed how digital product passports (DPPs) could facilitate a circular economy for textiles by providing transparent information about a garment throughout its life cycle. A DPPs is a concept that uses unique digital identifiers and decentralized ledger systems to provide extensive product-specific data across the product life cycle. This supports circularity by providing and making accessible the information necessary to enable re-X. As depicted in Figure 4, the DPP is intended to be a platform by which stakeholders across the product life cycle can input data that can be made selectively available to specified users.

iii. Standards Needed to Support Circular Textiles

Yarns & Fabrics

DPPs have the potential to facilitate textile circularity by improving sorting accuracy and recycling efficiency. Additionally, consumers can utilize DPPs for garment care and EoL options, promoting responsible consumption and recycling behaviors. The specific brand and style information contained in the DPP could also help enable garment repair (sourcing of replacement parts such as fasteners) or help market it for resale.

The EU recently released a Strategy for Sustainable and Circular Textiles [29], a comprehensive plan for transforming the textile industry focusing on sustainability, industrial resilience, and global cooperation. Various legislation is being implemented to support this strategy, including the Ecodesign for Sustainable Products Regulation (ESPR) and data collection and sharing through a mandated DPP [30, 31]. These regulations set requirements for product design, information transparency, and circularity practices. The ESPR and DPP are about data collection and creating a structured data system for efficient communication and data exchange among stakeholders.

Textile-specific DPP requirements and data criteria need to be established to address the unique challenges and opportunities of the textile industry. Standardized data formats and interoperability are crucial for efficient data exchange and effective utilization of DPPs. In the EU, industry associations like EURATEX [32] and consortiums like CIRPASS [33] play a vital role in providing input, developing standards, and facilitating the implementation of the regulations. Since the EU is leading the charge on implementing DPPs for textiles, their efforts are being closely followed globally to observe how this implementation is handled.

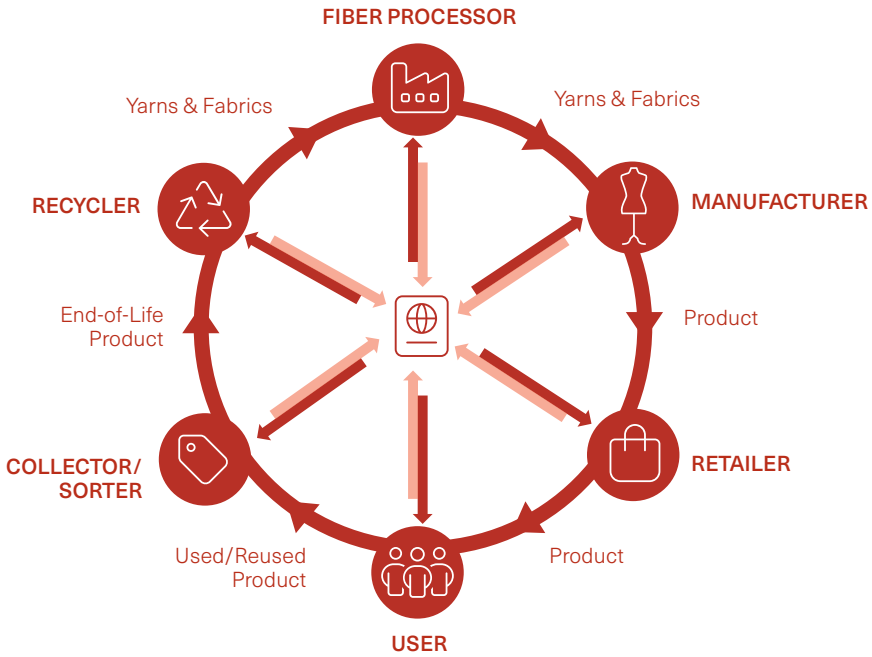

Figure 4 —DPPs are conceptualized as a data-sharing mechanism, by which stakeholders across the product life cycle input data that can be made available selectively to specified users. The arrows in the figure illustrate this concept, which represent the exchange of information to and from the passport throughout the product's life cycle.

iii. Standards Needed to Support Circular Textiles

While DPPs hold immense potential for a circular textile economy, their successful implementation requires addressing several challenges. Stakeholders who attended the workshop expressed concerns about data protection, implementation costs, data storage needs, and ensuring interoperability between different DPP systems. The impact of this evolving technology on recyclability and consumer privacy also necessitates careful consideration. Since the concept of DPPs is closely linked to digital labels, some participants were concerned that physical labels could be replaced through the DPP concept, where consumers would need to scan a code to obtain essential size and care information about a garment. Concern was also shared about the durability of digital identifiers (e.g., QR codes) throughout the life of the product.

Standardization across the DPP system is critical for ensuring data integrity and facilitating seamless data exchange. The EU is leading the charge through CEN/CENELAC in developing DPP standards. The U.S. could consider focusing standardization efforts on data format and exchange protocols, which could involve leveraging existing frameworks like the CIRPASS specifications [33]. Product identifiers and data carrier formats may be needed, and existing standards (e.g., [34]) could provide a strong foundation. Life Cycle Assessment (LCA) methods may rely on material and process information from DPPs so that standardized data formats could enable better and more transparent LCAs. Gaining widespread adoption of DPPs requires addressing concerns about cost, implementation complexities, and potential privacy violations. Data privacy safeguards and consumer control over data sharing must be prioritized to enable adoption. Different stakeholders can benefit from DPPs, including improved transparency, efficient compliance, enhanced consumer engagement, and optimized supply-chain management.

3.5.1. NEED FOR COLLABORATION AND PILOT PROJECTS

Collaboration among stakeholders including government agencies, industry associations, brands, and technology providers, is essential for overcoming implementation hurdles. International collaboration and standard setting to ensure seamless data exchange across borders is critical to a successful DPP concept. Pilot projects like the one proposed by participants, where DPP systems can be tested and refined, offer a valuable starting point. Industry associations like EURATEX and consortiums like CIRPASS can be vital in facilitating collaboration and knowledge sharing. Investments in research and development are crucial to explore and evaluate potential technological solutions like radio frequency identification (RFID) tags, virtual credentials, and digital watermarks. Standardization efforts should leave room for adaptability to future technological advancements to ensure the continued effectiveness of DPPs.

The EU's leadership in implementing DPPs for textiles can provide a valuable framework for other countries. International cooperation and harmonization of policies and standards are essential for creating a global circular textile system. Global stakeholders should consider developing a framework to guide the assessment of DPP concepts to ensure that implementation concerns are addressed. This could take the form of an assessment framework standard.

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3.5.2. STANDARDS NEEDS FOR DPPS

As other countries refine and implement their DPP strategies for textiles, the standards needed for DPPs in the U.S. will become more apparent. Communication and collaboration are needed to advance labels, e-labels, and possibly DPPs. The information that labels should include and the method of disseminating this information (e.g., physical, digital) also need further discussion and refinement. It is important to stay informed and involved with worldwide DPP efforts and their potential impact around the world.

iv. Next Steps

Throughout this workshop, many opportunities to advance textile circularity were identified. A natural starting point for this community is to consider working through the existing SDO efforts for textiles through ASTM and AATCC. Figure 5 provides a general roadmap for how standards might evolve to support textile circularity. Nearer-term standardization efforts are shown at the bottom or beginning of the roadmap, where the path is more straightforward. One place where significant effort could be directed is the identification and harmonization of terminology used throughout the textile ecosystem. Even during the workshop, speakers used several terms such as "grading" and "disruptors" that were well understood within their community but were not familiar to participants from other parts of the value chain. Care should be taken to identify and harmonize these terms as standards are developed in this space. Efforts are underway to develop data tools and identify important terms that need to be defined. In addition, several resources identified in Section 3.1 already define such terms.

The need for design guides came up repeatedly during the workshop. As mentioned in Section 3.4., the sustainability committee is already developing design guidelines for circular products. This could include a design guide for circular textiles aimed at informing textile designers and fashion brands about the impact of various choices available when designing a product. This could represent one of the earlier starting points for making a difference in the field of textile circularity. These design guides could discuss considerations such as EoL decisions; tradeoffs between design for recyclability and design for durability; recycled content specifications; and general best practices for circular design.

One of the greatest needs to help scale up the sorting, reuse, and recycling industries is better guides for sorting and grading of post-consumer textiles coupled with clearer input specifications that detail the types of materials that can be accepted by recycling processes, as discussed in Sections 3.2 and 3.3. These might include things like best practices for sorting methodologies and material component identification (e.g., near-infrared spectroscopy or visual inspection); classification guidelines for determining which pathway is best for individual textiles (e.g., resale or recycling); best practices for performing operations to prepare for recycling such as de-trimming; and harmonization of bale specifications so that sorters can sort for a broader variety of clients as opposed to individually sorting to each customer's specifications.

In the future, standards for labeling and digital product passports could potentially play a key role in circularity. As discussed in Section 3.5, details for developing digital product passports are being considered worldwide. ASTM should be involved in these conversations and understand how these discussions are evolving. Some considerations discussed in the workshop included standards for what information should be specified in a DPP or e-label; how those data should be collected and protected; and how it would remain part of the record associated with the garment (e.g., access to digital records, or durability of physical labels).

iv. Next Steps

A future where mature standards support transparency and validation of recycled content claims is achievable. Standards can help specify best practices for establishing chain of custody, verifying and reporting recycled content and tracking flows of textile waste. Standards can also support a robust ecosystem for textile circularity that includes conformity assessment and promotes consumer, brand, and recycler trust in a fair and validated system.

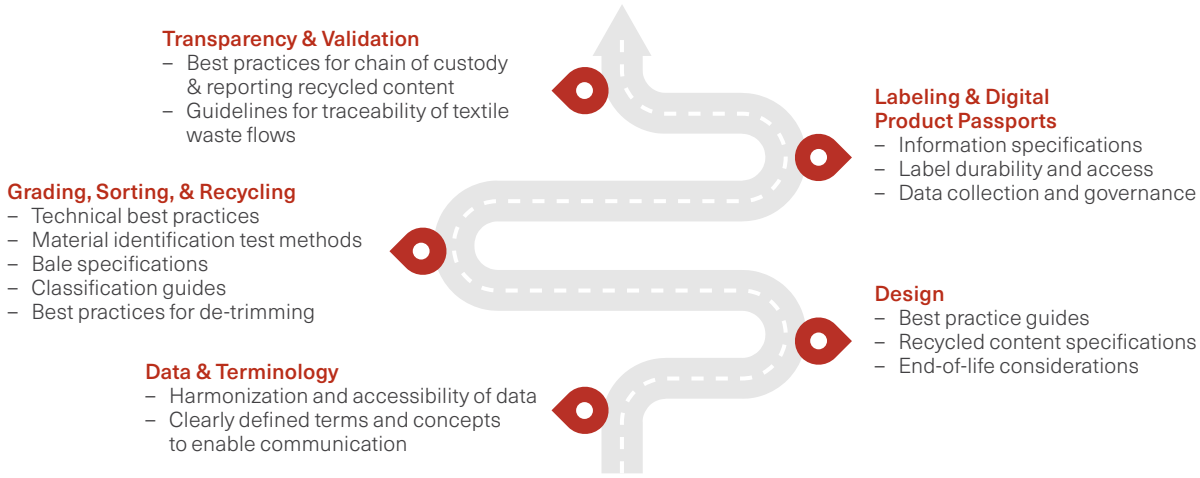

Figure 5 —ASTM Textile Circularity Standards Roadmap

Standards will be critical for the wide-scale deployment of new practices and methods in transitioning to a textiles CE. Rigorous, consensus-based, voluntary standards are necessary not only to help the industry begin deploying new practices but also to initiate work toward designing the education, training, infrastructure, and certifications that will be necessary for the shift to a CE. Stakeholders from across the textiles value chain and among the more extensive research and innovation communities came together in the NIST/ASTM/AATCC co-hosted workshop to identify standards needs for textiles circularity. These organizations and the broader textile production and recovery communities will rely on these learnings to bring a CE vision to fruition. At the same time, investments must be made to carry out the research needed to address the persistent challenges facing textile circularity and to train the next generation of the workforce to identify and deploy solutions to the challenges that emerge during the transition to a sophisticated circular ecosystem.

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Appendix A
Workshop Agenda

TUESDAY, OCTOBER 17

10:00 AM - 12:30 PM	**Plenary 1:** Textiles Circularity and the Role/Need for Standards **Session 1:** Developing Terminology Standards **Roundtables**
12:30 PM - 1 PM	**Break**
1 PM - 3 PM	**Session 2:** Specific Needs for Textile Sorting **Roundtables** **Discussion**

WEDNESDAY, OCTOBER 18

10:00 AM - 12:30 PM	**Plenary 2:** Perspectives on Circularity **Session 3:** Input Specification Needs for Recycling of Textiles **Roundtables**
12:30 PM - 1 PM	**Break**
1 PM - 3 PM	**Session 4:** Design for Cirularity **Roundtables** **Discussion**

THURSDAY, OCTOBER 19

10:00 AM - 12:30 PM	**Plenary 3:** Digital Product Passports **Session 5:** Standards Needs for Traceability and DPPs **Roundtables** **Discussion**

Appendix B
Workshop Presenters

PLENARY/SESSION	SPEAKER	ORGANIZATION
PLENARY 1	KC Morris Amy Costello Marisa Adler	U.S. National Institute of Standards and Technology ASTM Committee E60 on Sustainability RRS
SESSION 1	Vinnie Dias Deborah Callaway Virginia Cram	ASTM Committee D13 on Textiles ASTM Committee E60 on Sustainability Triangularity S.L.
SESSION 2	Louisa Hoyes Steven Bethel Beth Forsberg Alex Husted	Tomra Bank & Vogue Goodwill – Arizona Helpsy
PLENARY 2	Karla Magruder	Accelerating Circularity
SESSION 3	Parker Shannon Kevin Sullivan Catherine Armstrong Edmir Silva Adam Baruchowitz	Circ NREL Material Return Unifi Return to Vendor
SESSION 4	Natalie Banakis Randi Marshall Scott Kuhlman Taylor Hill Alice Hartley	Patagonia H&M Recircled Bleckmann Under Armour
PLENARY 3	Dirk Vantyghem Jan Merckx	EuraTex CIRPASS
SESSION 5	Julie Brown Gediminas Mikutis Shyaam Ramkumar Melissa Bastos Michael Colarossi	Eon Haelixa Circularise Cotton Incorporated Avery Dennison

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